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A study of boost converter with solar photovoltaic system for maximum energy efficiency

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Performance of a SPV system is dependent on temperature, array configuration, solar insolation, shading etc. The conversion of solar energy using SPV modules,change in insolation conditions which severely affect the efficiency and output power of the modules. Improvement in the efficiency of conversion of solar energy can be done by tracking the maximum power point of a PV module. Various types of MPPT charge controllers are available in the market. A dc-dc converter is an important component of a SPV system as it acts as an interface between the load and the SPV module. These dc-dc converters enhance the performance of the MPPT algorithms leading to an improvement in the overall efficiency of the SPV system. This paper presents the modeling and simulation of one diode equivalent circuit of solar photovoltaic module using MATLAB/SIMULINK™ along with the boost converter which gives an efficiency of 93.29%.

Key words: *Maximum power point tracking (MPPT), solar photovoltaic (SPV) characteristics, Boost converter*

1.0 INTRODUCTION

With growing population, economic and industrial development, the need to examine alternative sources for generation of electricity has become very important. Solar Photovoltaic (SPV) system is gaining importance as a renewable source due to zero fuel cost, negligible maintenance, low noise and wear due to the absence of moving parts, but limited by the high installation cost and low energy conversion efficiency. [1]. Solar energy production is clean, as it is emission free with continuous supply during day while being portable and scalable. Photovoltaic is the process of converting sunlight directly into electricity using solar cells in two phases. In the first phase solar radiations are absorbed within the semiconductor while in the second current / voltage is generated due to production of electrons-hole pairs by the incident radiations. The conversions of solar energy using SPV modules are associated with problems due to the change in insolation conditions. These changes severely affect the efficiency and output power of the SPV modules [2-4]. A great deal of research has been done to improve the efficiency of the PV modules. Several methods to track the maximum power point of a PV module have been proposed to improve the efficiency and products based on these methods are commercially available [2-4]. A MPPT is used for extracting the maximum power from the solar PV module and transferring it to the load [5-6]. A dc/dc converter (step up/ step down) transfers maximum power from the solar PV module to the load. It acts as an interface between the load and the module as shown in Figure 1 [6]. By changing the duty cycle the load impedance as seen by the source is varied and matched at the

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point of the peak power with the source so as to transfer maximum power [6]. MPPT techniques are needed to maintain the SPV array's operating at its MPP [7-8]. The basic dc-dc converters are buck, boost and buck-boost. The paper analyses the simulation results of a boost converter used in a SPV system.

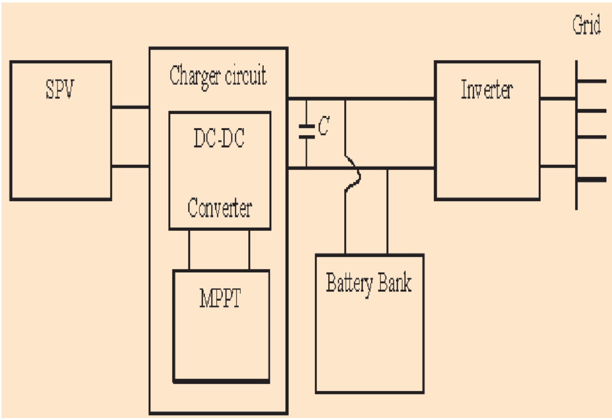

FIG. 1 BLOCK DIAGRAM OF THE SOLAR PHOTOVOLTAIC SYSTEM

2.0 SOLAR ARRAY CHARACTERISTICS

A solar photovoltaic (SPV) array consist of series and parallel combinations of several photovoltaic cells to increase the current and voltage.

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel along with inherent series (R_s) and parallel (R_p) resistances as shown in Figure 2. Series resistance is due to the opposition to the flow of electrons from n to p junction and parallel resistance is due to the leakage current.

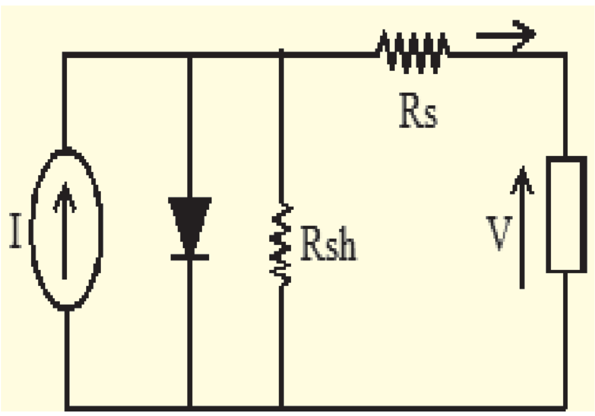

FIG. 2 SINGLE DIODE MODEL OF A SPV CELL

The output current from the photovoltaic array is

$$I = I_{sc} - I_d \quad ....(1)$$

$$I_d = I_o(e^{qV_d/kT} - 1) \quad ....(2)$$

Where I_o is the reverse saturation current of the diode, q the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38 X 10^{-23}J/K) and T is the junction temperature in Kelvin (K) [9].

From equation (1) and (2)

$$I = I_{sc} - I_o(e^{qV_d/kT} - 1) \quad ....(3)$$

$$I = I_{sc} - I_o(e^{q((V+IR_s)/nkT)} - 1) \quad ....(4)$$

Where, I is the photovoltaic cell current, V is the SPV cell voltage; T is the temperature (in Kelvin) and n is the diode ideality factor.

TABLE 1

COMMERCIALLY AVAILABLE 250 W MODULE PARAMETERS

Module parameters	Values
Nominal output Power (W)	250
Module efficiency (η,%)	15.00
operating temperature range (^{0}C)	-40 and 85
Voltage at PmaxVmpp(V)	30.7
Current at PmaxImpp(A)	8.16
Open-circuit voltage Voc(V)	38.1
Short-citcuit current Isc(A)	8.58
Number of modules per pallet	28

Figure 3 shows the commercially available 250 W solar panel. The maximum power point of a solar panel changes in accordance with the solar intensity, angle and panel temperature. The simulation of one-diode equivalent circuit is used in order to investigate I-V and P-V characteristics of aphotovoltaic module using Matlab/SIMULINK™ as shown in Figure 4 [10].

Figures 5 and 6 show the I-V and P-V characteristics of a SPV panel. Figures 7 and 8 show the I-V and P-V characteristics of a SPV with varying temperatures respectively.

FIG. 3 COMERCIALLY AVAILABLE 250 W SOLAR PANEL

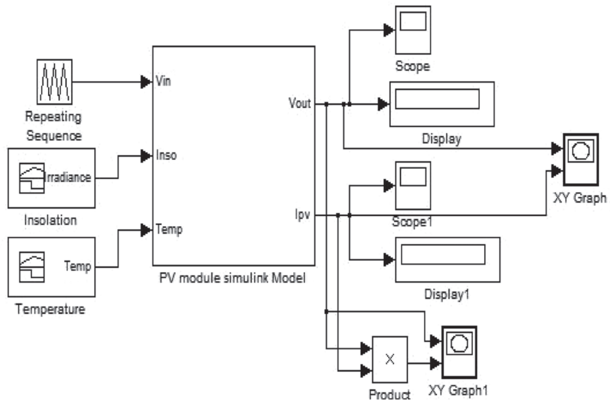

FIG. 4 SIMULINK MODEL OF A SPVMODEL

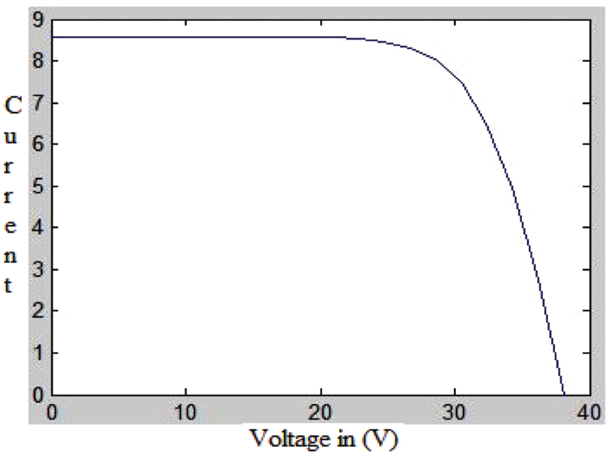

FIG. 5 I-V CHARACTERISTICS OF A SOLAR PANEL

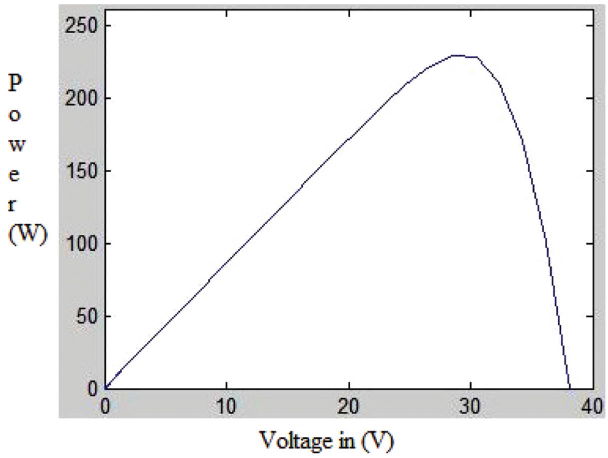

FIG. 6 P-V CHARACTERISTICS OF A SOLAR PANEL

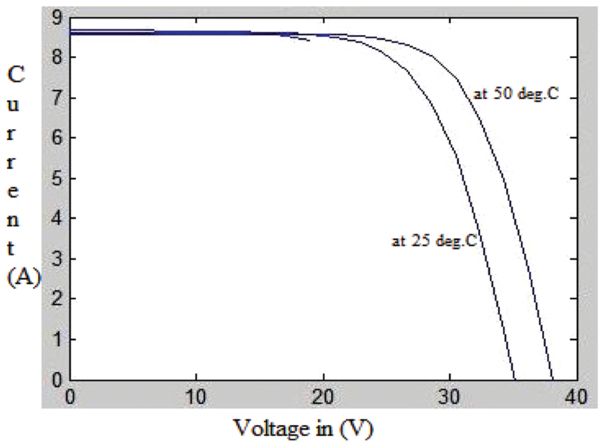

FIG. 7 I-V CHARACTERISTICS WITH VARYING TEMPERATURE

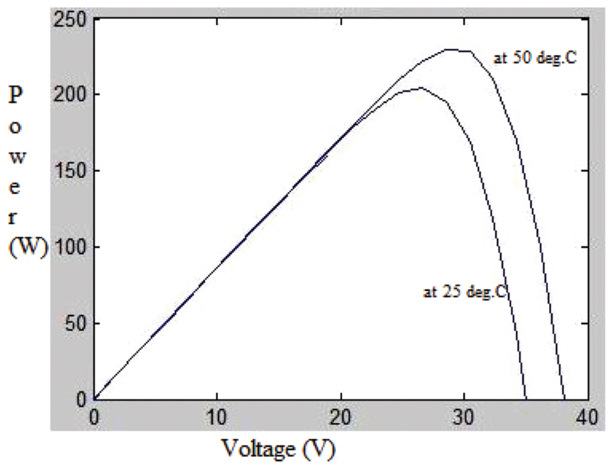

FIG. 8 P-V CHARACTERISTICS WITH VARYING TEMPERATURE

3.0 DC TO DC CONVERTER

A DC-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. The DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drive applications. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. The heart of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for a different purpose: regulating the input voltage at the PV MPP and facilitate load matching for maximum power transfer.

A switching converter consists of capacitors, inductors, and switches. All these devices ideally do not consume any power, resulting in high efficiencies of switching converters. If the device is in the on-state, the voltage drop across it will be close to zero and hence the dissipated power will be very small. During the operation of the converter, the switch will be switched at a constant frequency f_s with an ON-time of DT_s, and an OFF time of $(1 - D)T_s$, where T_s is the switching period $(1/f_s)$ and D is the duty ratio of the switch $(D \in [0; 1])$ as shown in Figure 9.

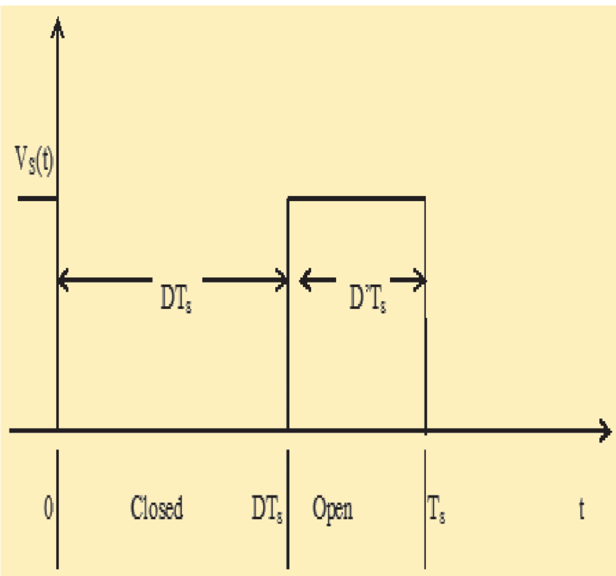

FIG. 9 IDEAL SWITCH VOLTAGE VS, DUTY RATIO D, AND SWITCHING PERIODTS

4.0 BOOST CONVERTER

The boost converter is also known as the step-up converter as shown in Figure 10. The name implies it's typical application of converting a low input-voltage to a high out-put voltage, essentially functioning like a reversed buck converter[11-13]. Figure 11 shows the simulated boost converter circuit.

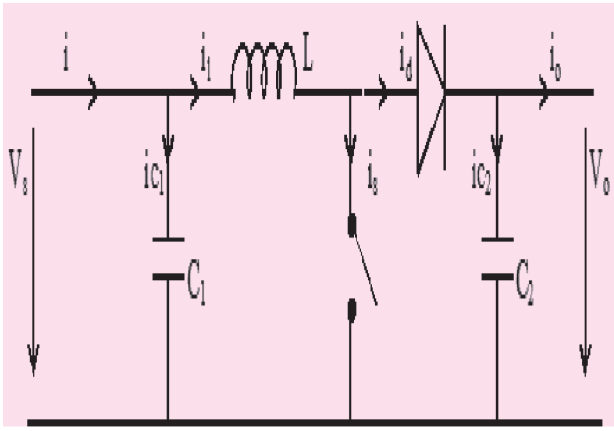

FIG. 10 IDEAL BOOST CONVERTER CIRCUIT

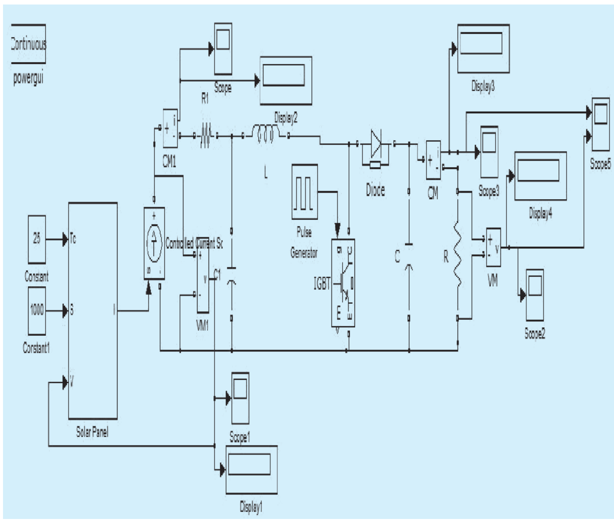

FIG. 11 SIMULATED BOOST CONVERTER CIRCUIT

During the ON time interval DT_s of the switching period T_s, the closed switch connects the input through the inductor to ground resulting in the flow of high current. The diode is reverse biased to prevent the flow of inductor current through the load. After the switch is opened in during OFF time interval $(1- DT_s)$ of the switching period, the nature of the inductor prevents the discontinuity in the current flow, and the high current through the now forward biased diode leads to an increase in high voltage which is applied across the load.

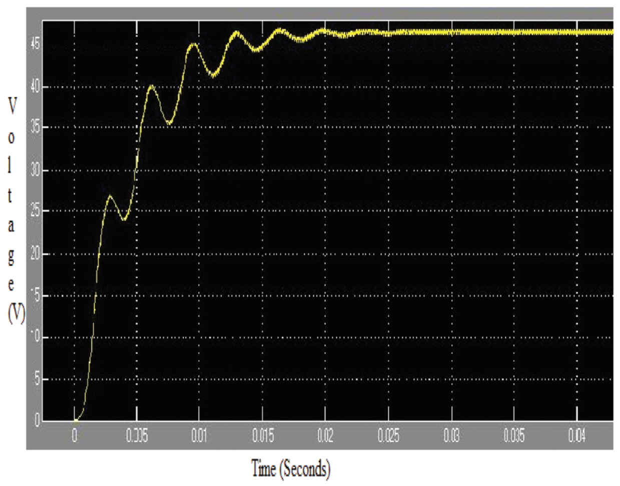

FIG. 12 OUTPUT VOLTAGE OF BOOST CONVERTER CIRCUIT

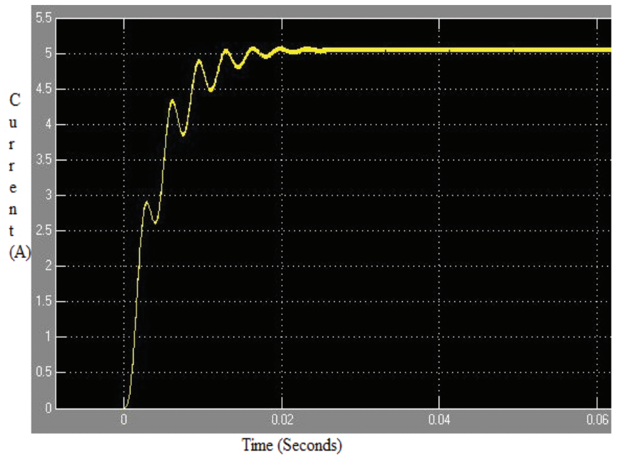

FIG. 13 OUTPUT CURRENT OF BOOST CONVERTER CIRCUIT

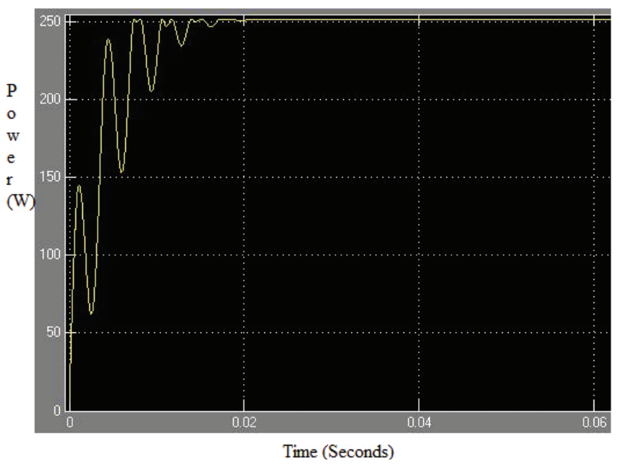

FIG. 14 INPUT POWER OF BOOST CONVERTER CIRCUIT

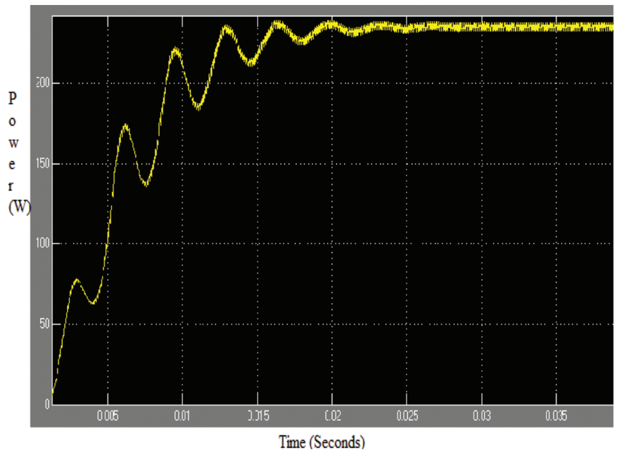

FIG. 15 OUTPUT POWER OF BOOST CONVERTER CIRCUIT

The output voltage and current of the boost converter are shown in Figures 12 and 13 respectively.

The output ripple voltage varies from 46.3V to 46.8V while the output ripple current is varying from 5.03A to 5.08A.

The input and output power of the converter are shown in Figures 14 and 15 respectively for calculating the efficiency of the simulated boost converter.

The input power measured from the simulated circuit is 251.9W and the output power measured is 235W. The efficiency of the system is 93.29%.

5.0 CONCLUSIONS

One simple solar panel that has standard value of insolation and temperature has been shown. The simulated solar panel exhibits different I-V and P-V characteristics with variation in the insolation and temperature as shown. With this modeldifferent dc-dc converters can be simulated and the performance of the solar photovoltaic system can be analyzed.

The boost converter circuit simulated in MATLAB/SIMULINK™ gives an efficiency of 93.29% with an output ripple voltage of 0.5V and output ripple current of 0.05A.

By using this model of the boost converter, various MPPT algorithms can be simulated and their performance analyzed.

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